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EXHAUST EMISSION TRAVERSE INVESTIGATION OF A JT3D-1 TURBOFAN EN--ETC(U)
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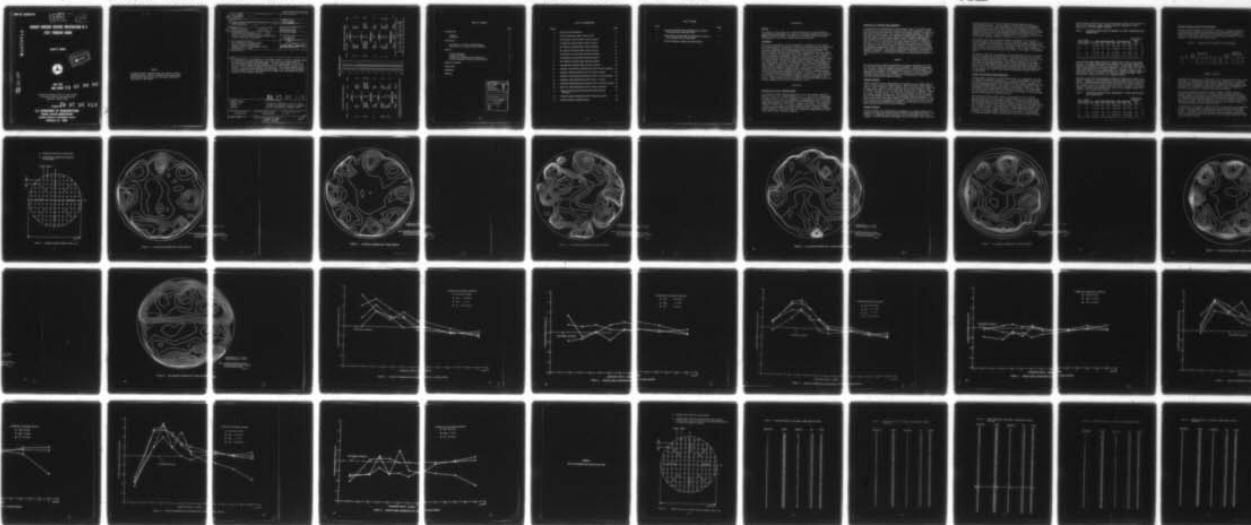
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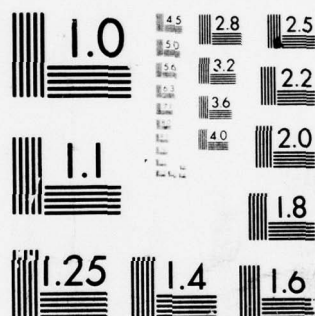
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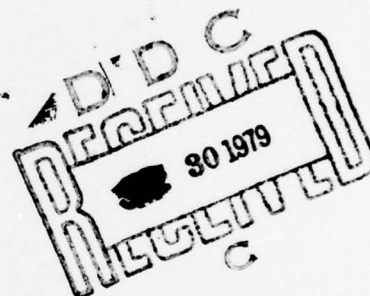
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EXHAUST EMISSION TRAVERSE INVESTIGATION OF A JT3D-1 TURBOFAN ENGINE

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Gerald R. Slusher



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JUNE 1979
FINAL REPORT

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Prepared for 79 07 30 052

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
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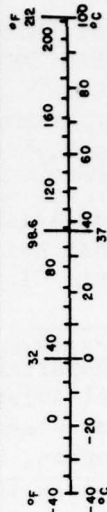
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16. Abstract An investigation of the emissions in the exhaust plume of a JT3D-1 turbofan engine was conducted to optimize the shape, size, and location of fixed probes for acquiring representative emission samples. Traverse measurements of 153 points over the exhaust nozzle were accomplished with the sample points located in the corners of 2-inch squares forming a traverse grid. The average emission levels, contours, and profile distributions were determined. The predicted performances of area weighted cruciform and diamond probe designs were calculated from interpolations of the traverse contours.		
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	2.5	centimeters	cm
ft	feet	30	meters	m
yd	yards	0.9	kilometers	km
mi	miles	1.6		
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
km	kilometers	1.1	yards	yd
		0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



* 1 m = 2.54 centimeters. For other exact conversions and more charts and tables, see NBS Mon. Publ. 286, Units of Length and Mass, Price \$2.25, SD Catalog No. C13.10-286.

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INTRODUCTION

PURPOSE.

The purpose of this report is to define variability in aircraft turbine engine emission measurements as related to acquiring representative emission samples with fixed probes. The results of an exhaust emission traverse investigation of the JT3D-1 turbofan engine are reported.

BACKGROUND.

The Clean Air Amendments of 1970 (reference 1) specified that the United States Department of Transportation (DOT) and the Federal Aviation Administration (FAA) promulgate regulations enforcing the aircraft engine emission standards established by the Environmental Protection Agency (EPA). Two major variability problems regarding emission measurements have been identified by industry and Government study teams (reference 2). One problem area affecting emission measurements involved the effect of changes in ambient weather conditions, particularly temperature and humidity, on emission levels. The second problem involved acquiring a representative emission sample from the exhaust plume. The FAA was commissioned to conduct an investigation of these variability problems at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey. As part of this study, ambient temperature and humidity correction factors were developed for exhaust emissions from two classes of turbine engines (reference 3). Studies of the traverse emission plots indicated that the use of fixed probing techniques to provide representative samples is feasible (reference 4). The results of that portion of the investigation designed to traverse and measure emissions in the exhaust plume of the JT3D-1 turbofan engine is presented in this report. Emission sample probe investigation of mixed-flow JT8D-11 and TF30 turbofan engines can be found in references 5 and 6.

DISCUSSION

DESCRIPTION OF JT3D-1 TURBOFAN ENGINE.

The commercial JT3D-1 engine incorporates a front fan having a bypass-to-engine air flow ratio of approximately 1.4 to 1. The fan air is discharged through a short duct and is not mixed with the primary or core exhaust gases. The pressure ratio across the compressor is approximately 13 to 1, and the engine which develops 17,000 pounds of thrust incorporates eight can-annular combustion chambers and four struts to support the turbine. The mechanical condition of the engine, including excessive vibration levels, precluded traverse emissions testing at engine conditions above idle power. Emission levels presented in this report are not necessarily representative of those levels from current production engines.

DESCRIPTION OF TRAVERSE PROBE MECHANISM.

A detailed traverse investigation of the exhaust plume of the JT3D-1 engine was necessary to establish actual emission levels and to generate the data base for preparing the emission contours and profiles required for design and evaluation of fixed probes. The traverse probe mechanism shown in figure 1 was constructed to position the single-point sample probe remotely within a vertical plane behind the engine exhaust nozzle. Emission measurements were recorded on a 2-inch grid located in the vertical plane at axial distances of 2 and 10 inches behind the engine exhaust nozzle. In addition to the points on the 2-inch grid, 16 measurement points were added to improve the accuracy of the profile analysis along the 45 degree (°) and 90° radii. The additional measurements were not included when calculating the traverse average concentration. The traverse sample grid consisting of 153 points is depicted in figure 2. Emissions were measured at the points identified in the traverse grid, at the two axial positions, and engine power condition of idle.

RESULTS

The nozzle traverse emission measurements and engine performance data base for the JT3D-1 engine are tabulated in the Appendix. Emission measurements are corrected to standard ambient temperature of 59 degrees Fahrenheit (°F) and 0 specific humidity in accordance with reference 3. These emission measurements are included in the Appendix for further analysis and comparison with other probe results and to develop and recommend probe designs for acquiring representative emission samples.

TRAVERSE CONTOURS.

Exhaust emission traverse measurements were acquired at idle engine power at 2 and 10 inches behind the exhaust nozzle. Emission maps of carbon dioxide (CO₂) in units of percent, carbon monoxide (CO), total hydrocarbons (THC), and nitrogen oxides (NO_x) in units of parts per million (ppm) volume are shown in figures 3 through 6 for the 2-inch axial position and in figures 7 through 10 for the 10-inch location. The variation in pollutant concentration and the probing problems are apparent. The striking feature of the iso-emission maps is the apparent patterns from the individual combustion chambers. The patterns from each of the eight combustion chambers are evidenced by the high local levels of the emissions in the patterns. Swirl may be noted in the CO and CO₂ emissions by comparing the changes in the patterns as the probe was moved from the 2-inch to the 10-inch location.

TRAVERSE PROFILES.

Traverse profiles were established by averaging four traverse emission measurements acquired from constant-radius positions each separated by 90°. The radius, i.e., immersion depth, was varied and four additional points were averaged. Traverse emission measurements on the four radii of 45°, 135°, 225°, and 315° were averaged.

and 315° (referred to as the 45° location) were averaged for each of seven immersion depths. A second group of traverse emission measurements located along the four radii coinciding with the vertical and horizontal centerlines (referred to as the 90° location) were averaged for each of nine immersion depths. Ratios were then established by dividing the four averaged emission concentrations at each immersion depth by the overall traverse average concentration. Ratios of emissions at 45° and 90° were then plotted against their immersion depths on figures 11, 13, 15, and 17.

The profile plots show the emission slopes or gradients in the exhaust in the JT3D-1 engine. The profile levels were affected by their relation to combustion chamber emission patterns. Traverse average emission concentrations were located at 43 to 46 percent of the radius on the 45° and 90° radii. Therefore, emission concentration levels equivalent to the traverse average were located at immersion depths greater than halfway to the center of the exhaust plume.

The emission index (EI) was defined as the mass emission rate of a pollutant in units of pounds per thousand pounds of fuel (lbs/1000 lbs fuel) as determined from carbon balance calculations. The EI was calculated for each of the averaged emission concentrations at each immersion depth on the 45° and 90° radii as previously described. Ratios were established by dividing the three EI's at each immersion depth by the overall traverse average index. Ratios of EI's were then plotted against the immersion depth in figures 12, 14, 16, and 18. The EI gradients with immersion depth were essentially zero, and the indices are closer to the traverse average when compared with the concentrations.

DIAMOND AND CRUCIFORM PROBE PREDICTIONS.

A square probe, referred to as the diamond probe, was recommended by the FAA for emission measurement (reference 7). The probe was designed in the shape of a square in order to clear the exhaust centerbody common to a number of aircraft-installed engines, but was rotated 45° for emission sampling purposes, thus the name diamond probe. The probe is illustrated in figure 19. The recommended 12-point probe design sampled at 62 percent of the nozzle radius and featured three sample points in each nozzle quadrant. The probe design was also studied for the 22.5° radii location in an attempt to position sample points between combustion emission patterns.

Calculated performance results based on interpolations of the traverse maps and related in percent of the traverse average on a concentration and emission index basis are tabulated in table 1. The emission concentrations were somewhat higher than the traverse average at the 2-inch axial position and were significantly higher than the traverse average at the 10-inch location. Also included in table 1 are measurement of sample efficiency defined as the ratio of carbon balance fuel-to-air ratio to the measured fuel-to-air ratio expressed in percent. Sample efficiencies at the 2-inch and 10-inch axial positions were somewhat higher (richer) than 100 percent. The calculated or predicted emission indices were generally closer to the traverse average.

The performance deterioration at the 10-inch axial position was attributed to swirl of the combustion chamber emission patterns resulting in richer emissions at the probe sample locations.

TABLE 1. CALCULATED DIAMOND PROBE PERFORMANCE--12 POINTS INTERPOLATED FROM TRAVERSE MAPS

Axial Position (Inches)	Angular Position (Degrees)	Run No.	Percent Traverse Concentration				Percent Traverse EI			Sample Efficiency F/ACB X100
			CO ₂	CO	THC	NO _x	CO	THC	NO _x	F/A _M (%)
2	45	3	105.4	108.8	103.0	110.4	103.4	97.9	104.9	103.4
10	45	7	114.8	117.4	113.9	115.0	102.2	99.2	100.0	114.3
2	22.5	3	108.2	107.0	103.5	114.4	99.6	96.4	106.7	105.6
10	22.5	7	117.9	113.1	109.2	113.8	96.9	93.6	97.4	116.2

The cruciform probe design featured 12 sample points, three in each nozzle quadrant. The sample points were area weighted for the nozzle diameter by locating the orifices at centers of equal areas. Interpolations and calculations were completed for the probe sampling on the 45°, 135°, 225° and 315° radii, identified as the 45° angular position. The sample points of the probe were rotated 22.5° counterclockwise in an attempt to sample between the high emission levels existing in the combustion emission patterns. This location was referred to as the 22.5° angular position.

Calculated cruciform probe performance results as related in percent to the traverse average, on a concentration and emission index basis, are listed in table 2. Excellent sample efficiencies were calculated for the 2-inch axial and 45° angular position and the 10-inch axial and 22.5° angular position. The emission indices and concentrations were good as related to the traverse average. Emission concentrations were closer to the traverse average than results for the diamond probe design.

TABLE 2. CALCULATED CRUCIFORM PROBE PERFORMANCE--12 POINTS AREA WEIGHTED FROM TRAVERSE MAPS

Axial Position (Inches)	Angular Position (Degrees)	Run No.	Percent Traverse Concentration				Percent Traverse EI			Sample Efficiency F/ACB X100
			CO ₂	CO	THC	NO _x	CO	THC	NO _x	F/A _M (%)
2	45	3	101.0	104.3	104.8	96.7	102.4	103.0	95.1	100.0
10	45	7	106.7	108.2	107.1	103.4	101.3	100.3	96.7	106.3
2	22.5	3	98.9	97.6	97.4	99.6	98.7	98.8	110.8	96.9
10	22.5	7	101.1	98.4	96.1	102.5	94.6	95.8	102.0	99.9

TRAVERSE EMISSION INDICES AND EFFICIENCIES.

Traverse average emissions indices were corrected for ambient temperature and humidity in accordance with reference 3 and are tabulated in table 3. Engine performance with observed and corrected indices are included in table A-3. The emission levels are not necessarily representative of contemporary JT3D-3B and JT3D-7 engine models.

TABLE 3. TRAVERSE EMISSION INDICES AND EFFICIENCIES

Mode	Run No.	Axial Position (Inches)	Emission Index lb/1000 lb Fuel			CO ₂ (%)	F/A _M	F/A _{CB}	Sample Efficiency (%)	Corrected Emission Index lb/1000 lb Fuel		
			CO	THC	NO _x					CO	THC	NO _x
Idle	3	2	96.26	179.27	2.19	1.17	.00724	.007251	100.2	94.77	159.16	2.51
Idle	7	10	84.51	131.20	3.02	1.19	.00686	.006956	101.4	83.74	122.26	3.53

SUMMARY OF RESULTS

Emissions were measured on a 2-inch grid in the exhaust plume of JT3D-1 turbofan engine. Traverse emission measurements were completed at idle engine power at axial locations of 2 and 10 inches behind the exhaust nozzle. The objectives were to establish a data base as required for calculating average emissions and to generate the maps and profiles required for design and evaluate fixed probes for acquiring representative samples.

The traverse emission maps show the eight combustion chamber emission patterns existing downstream of the exhaust nozzle illustrating high local emission levels in the patterns. The concentration profiles are effected by the combustion patterns being higher than the traverse average at low immersion depths then decreasing to somewhat less than the traverse average at the center of the plume. The emission index profiles are essentially flat and approximately agree with the traverse average.

Interpolation of the emission contours from the traverse maps was accomplished to predict the performance of diamond and cruciform emission sample probe designs. The diamond and cruciform probes were equally good for emission indices. The diamond probe was moderately high for emission concentrations, while the emission concentrations from the cruciform probe design were close to the traverse average.

CONCLUSIONS

Based on the results of the emission traverse measurements of the JT3D-1 turbofan engine at idle power, it is concluded that:

1. The exhaust plume is characterized by combustion chamber emission patterns featuring high local emission levels which affect the representativeness of samples provided by fixed probes.
2. Predicted performance of diamond and cruciform probe designs were considered good for emission indices.
3. Cruciform probe performance based on calculations of traverse measurements was better than diamond probe performance for emission concentrations. Sample efficiencies were indicated to be good.

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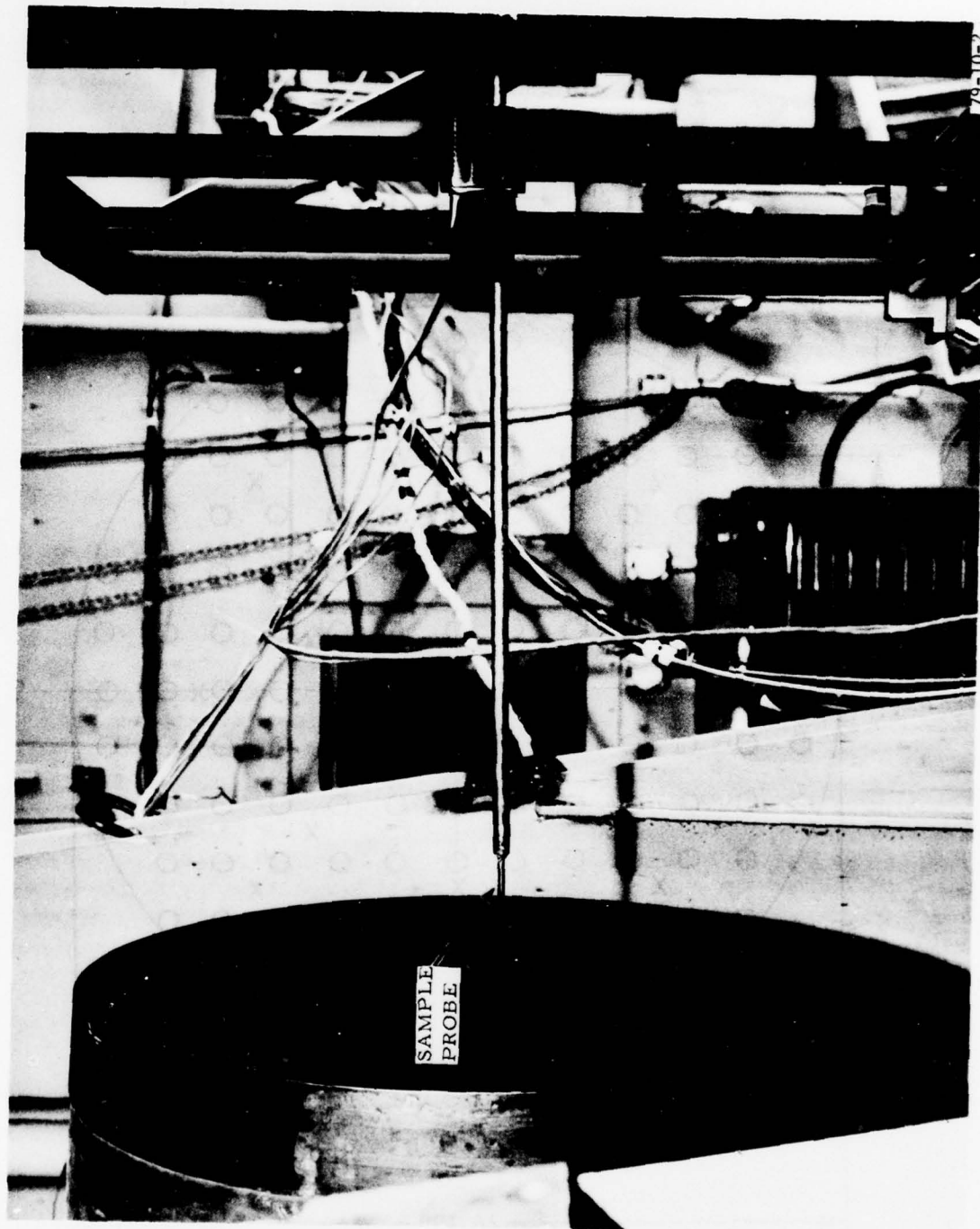


FIGURE 1. TRAVERSE PROBE MECHANISM

○ POINTS LOCATED ON 2-INCH GRID

× ADDITIONAL POINTS FOR PROFILE
EVALUATION

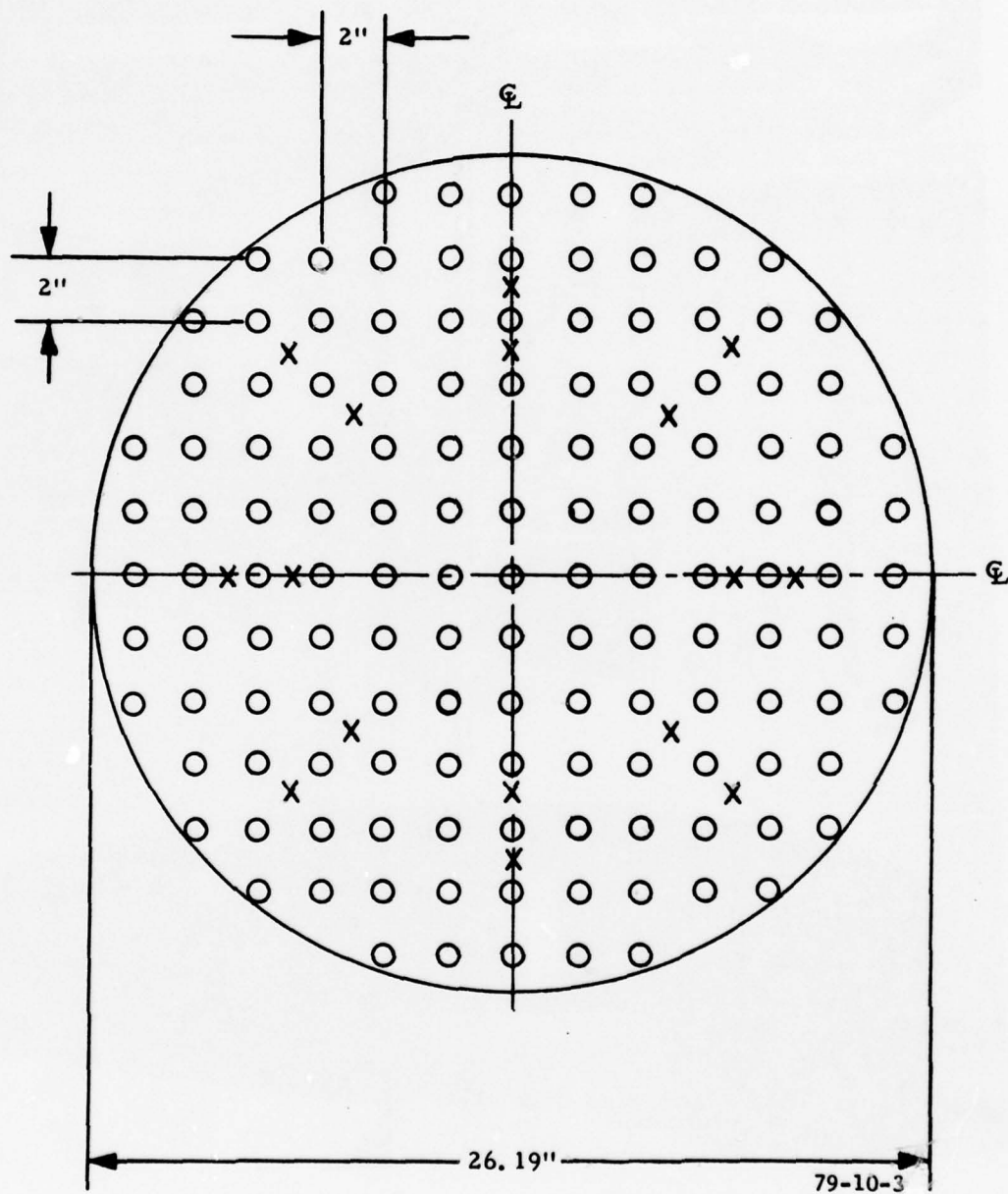


FIGURE 2. TRAVERSE EMISSION SAMPLE POINTS (153)



FIGURE 3. CO₂ EMISSION TRAVERSE MAP--2-INCH LOCATION

CO₂ = 1.17%

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FIGURE 4. CO EMISSION TRAVERSE MAP—2-INCH LOCATION

PPM
94.77 EI

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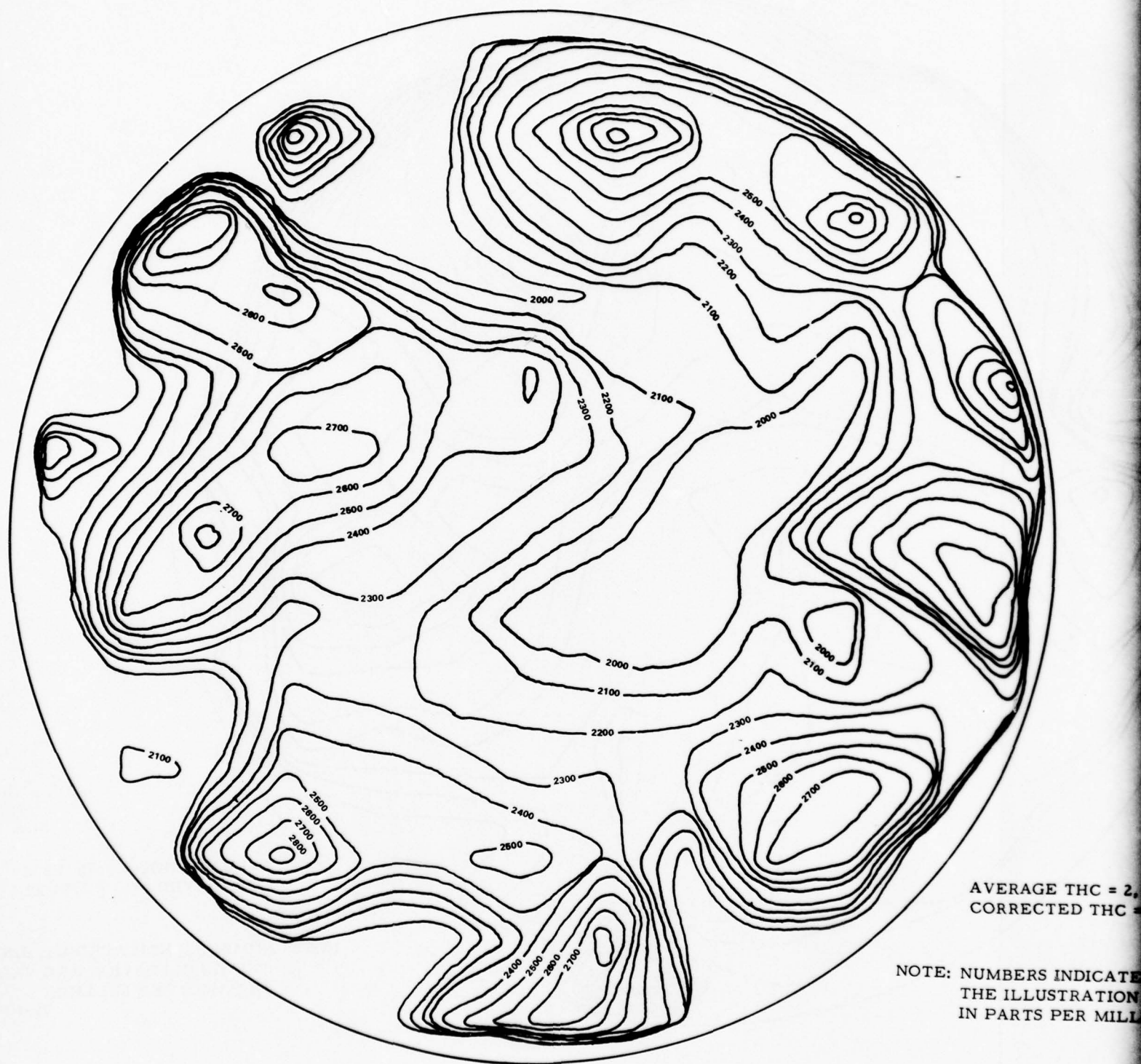


FIGURE 5. THC EMISSION TRAVERSE MAP--2-INCH LOCATION

C = 2,297 PPM
THC = 159.16 EI

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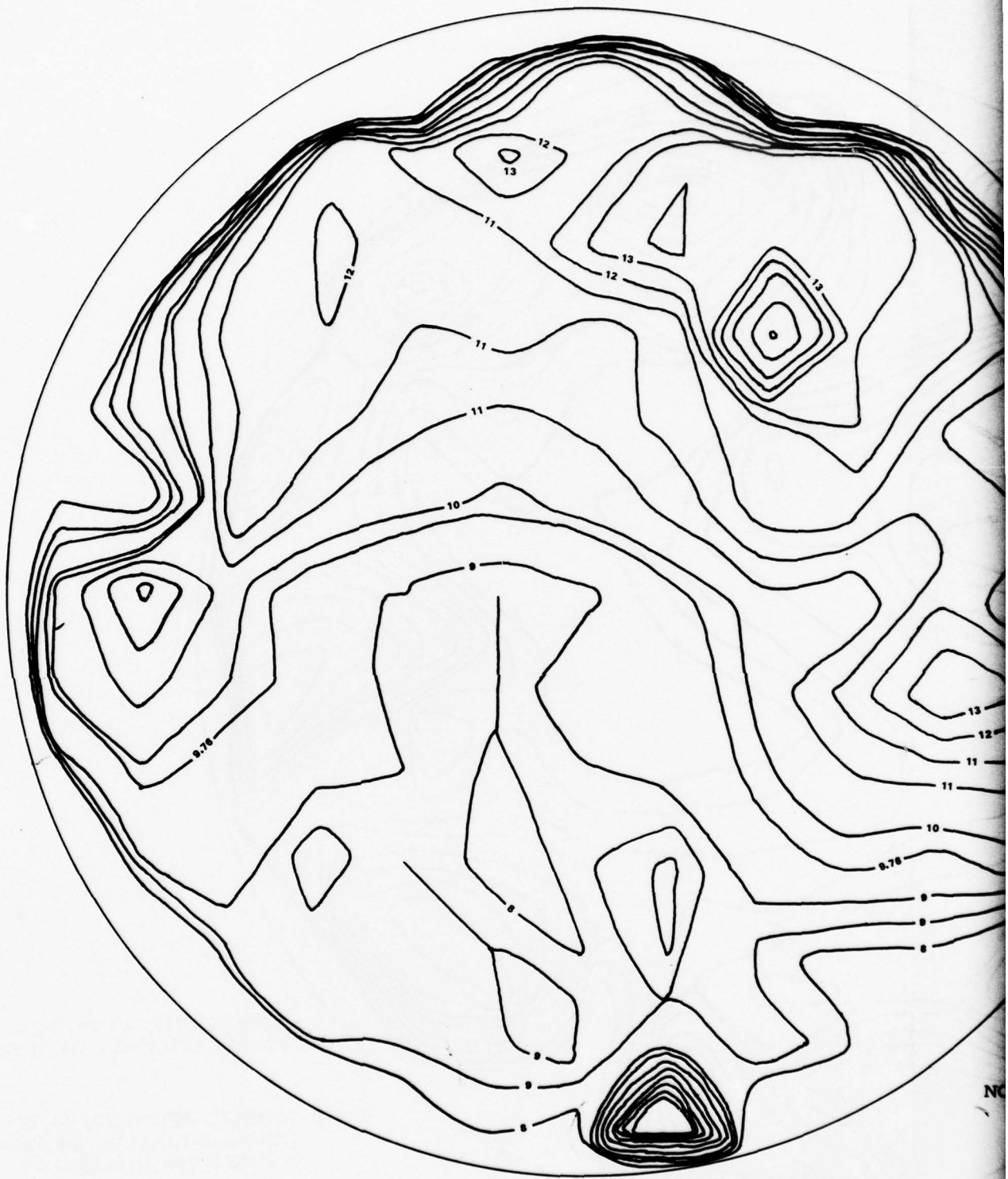
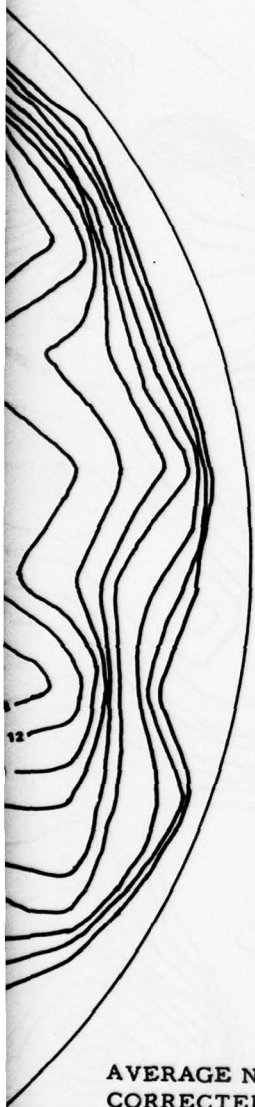


FIGURE 6. NO_x EMISSION TRAVERSE MAP--2-INCH LOCATION



AVERAGE NO_x = 9.76 PPM
CORRECTED NO_x = 2.51 EI

NOTE: NUMBERS INDICATED WITHIN
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IN PARTS PER MILLION.

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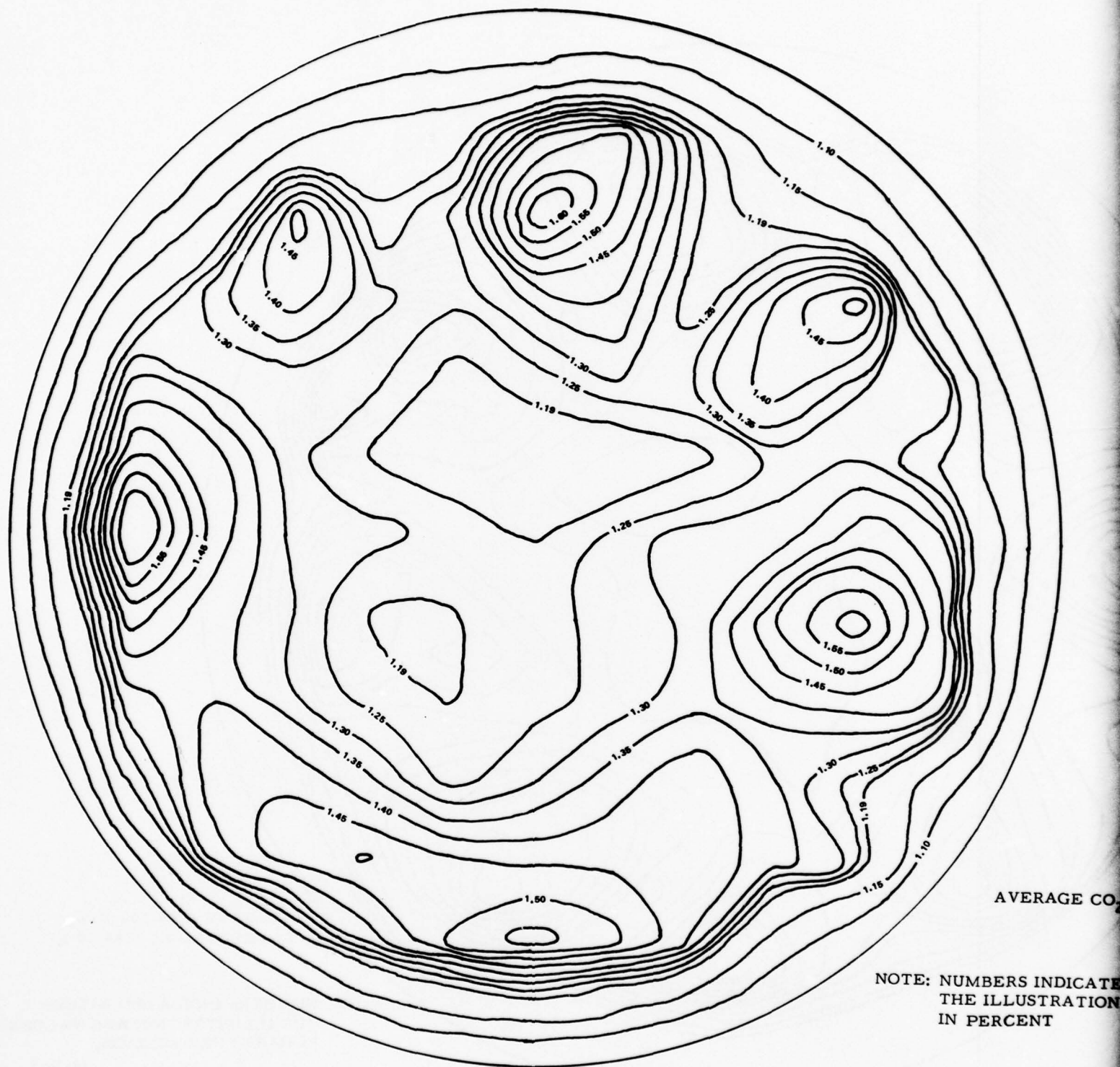


FIGURE 7. CO₂ EMISSION TRAVERSE MAP--10-INCH LOCATION

CO₂ - 1.19%

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VALUES ARE VALUES

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FIGURE 8. CO EMISSION TRAVERSE MAP--10-INCH LOCATION

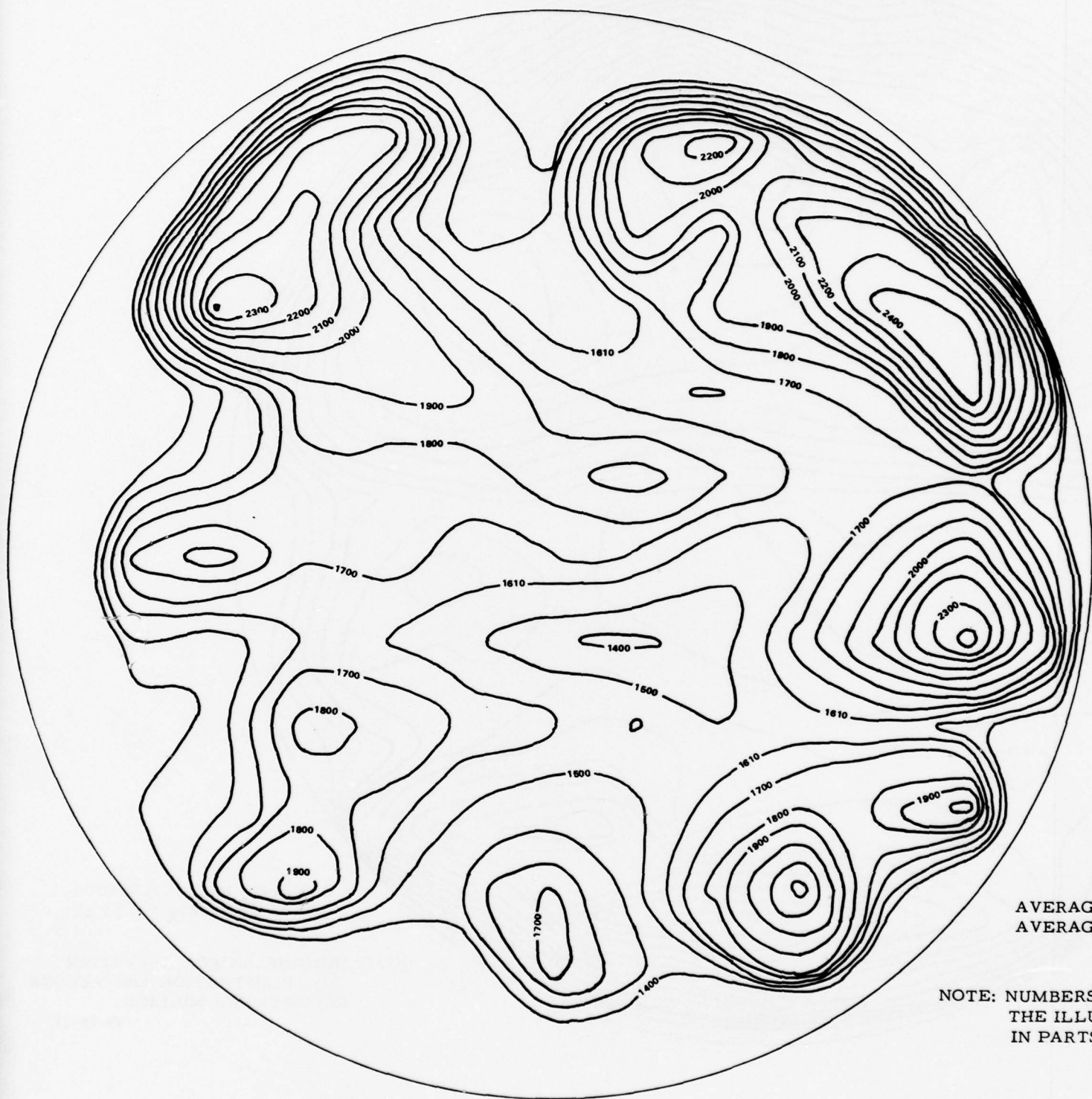


AVERAGE CO = 594 PPM
CORRECTED CO = 83.74 EI

NOTE: NUMBERS INDICATED WITHIN
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IN PARTS PER MILLION.

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2



AVERAGE THC = 1
AVERAGE THC = 1

NOTE: NUMBERS INDICATE
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IN PARTS PER MIL

FIGURE 9. THC EMISSION TRAVERSE MAP--10-INCH LOCATION

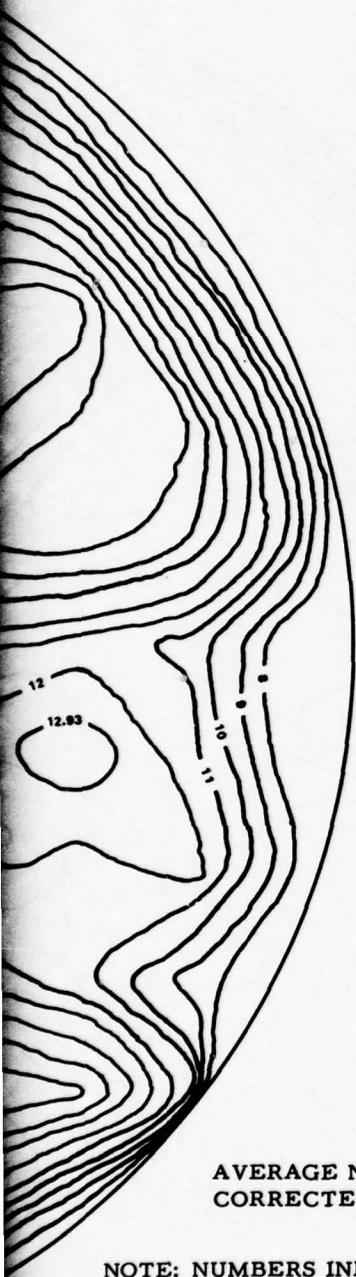
= 1609.6 PPM
= 122.26 EI

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ION ARE VALUES
MILLION.

79-10-10



FIGURE 10. NO_x EMISSION TRAVERSE MAP--10-INCH LOCATION



AVERAGE $\text{NO}_x = 12.93 \text{ PPM}$
CORRECTED $\text{NO}_x = 3.53 \text{ EI}$

NOTE: NUMBERS INDICATED WITHIN
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IN PARTS PER MILLION.

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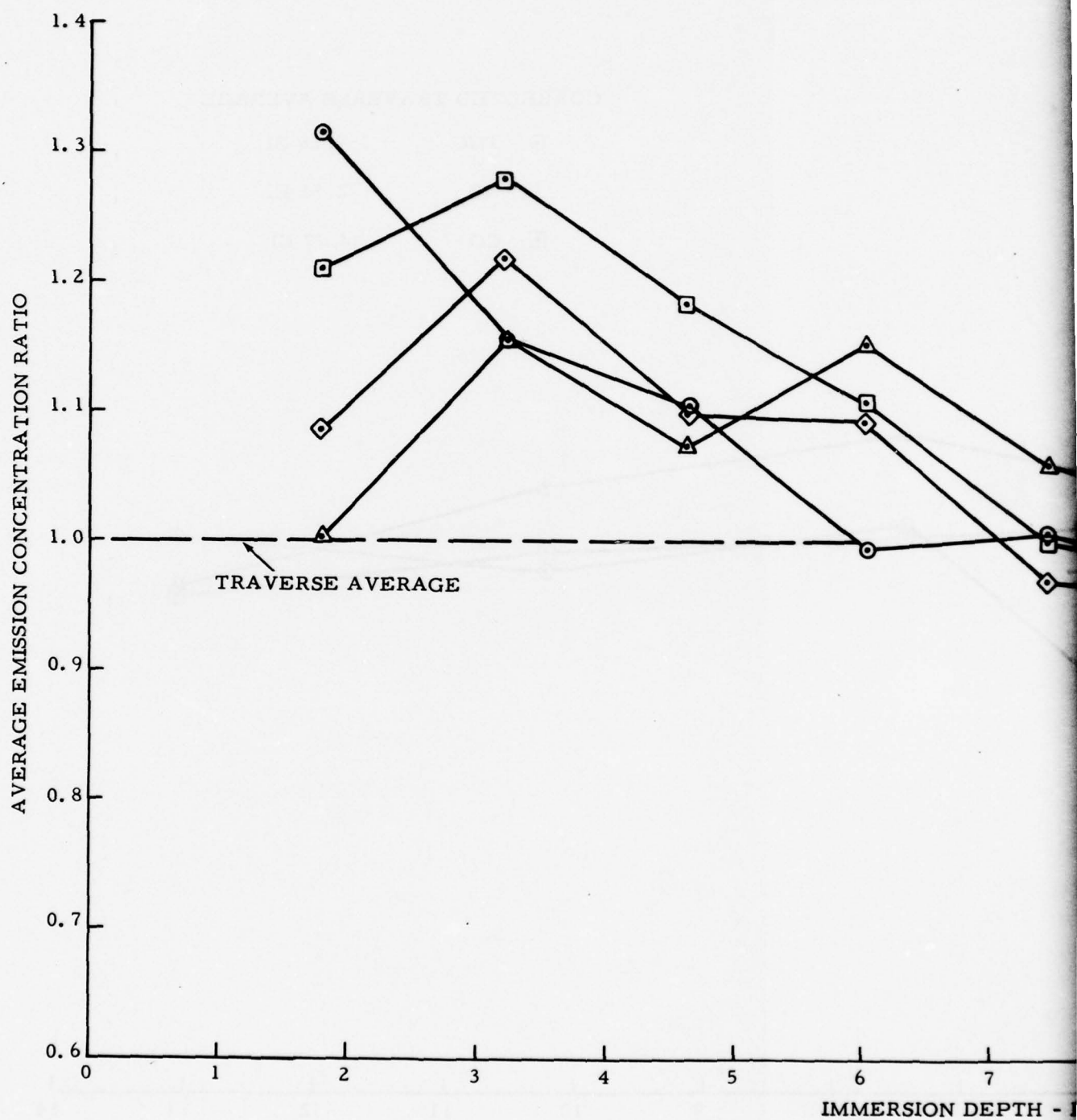


FIGURE 11. EMISSION CONCENTRATION DISTRIBUTION

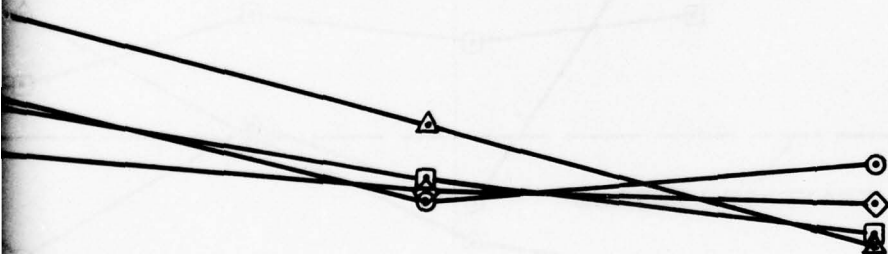
OBSERVED TRAVERSE AVERAGE

⊙ THC 2296.64 PPM

△ NO_X 9.76 PPM

◇ CO₂ 1.17 %

□ CO 706.42 PPM



INCHES 8 9 10 11 12 13 14 79-10-12

ION--45°--2-INCH LOCATION

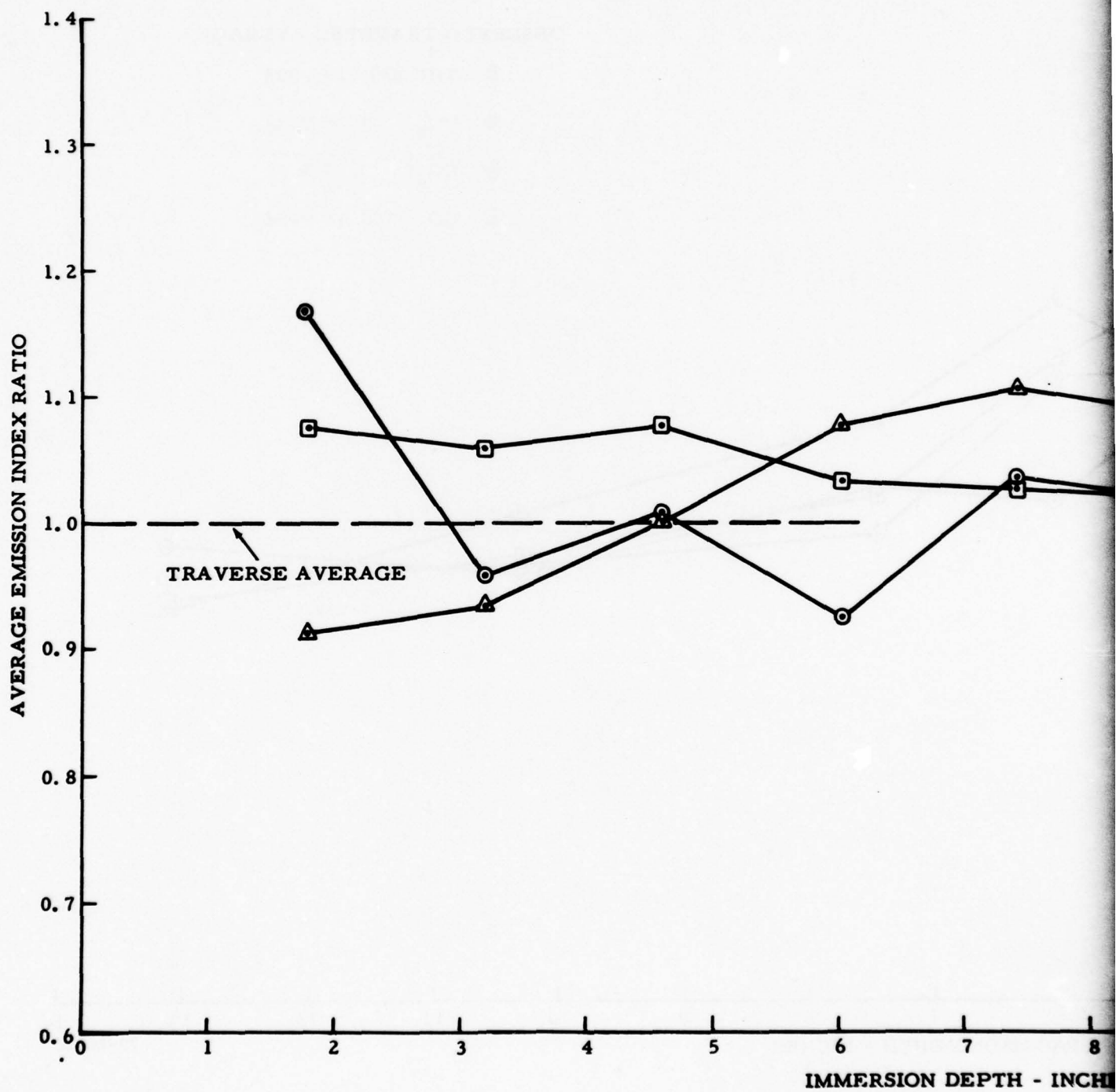
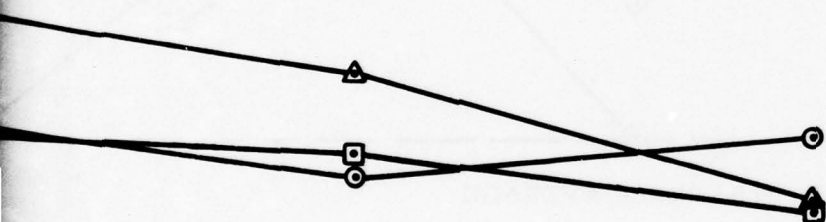


FIGURE 12. EMISSION INDEX DISTRIBUTION—49

CORRECTED TRAVERSE AVERAGE

⊙	THC	159.16 EI
△	NO _X	2.51 EI
□	CO	94.77 EI



9 10 11 12 13 14

79-10-13

IES

5°--2-INCH LOCATION

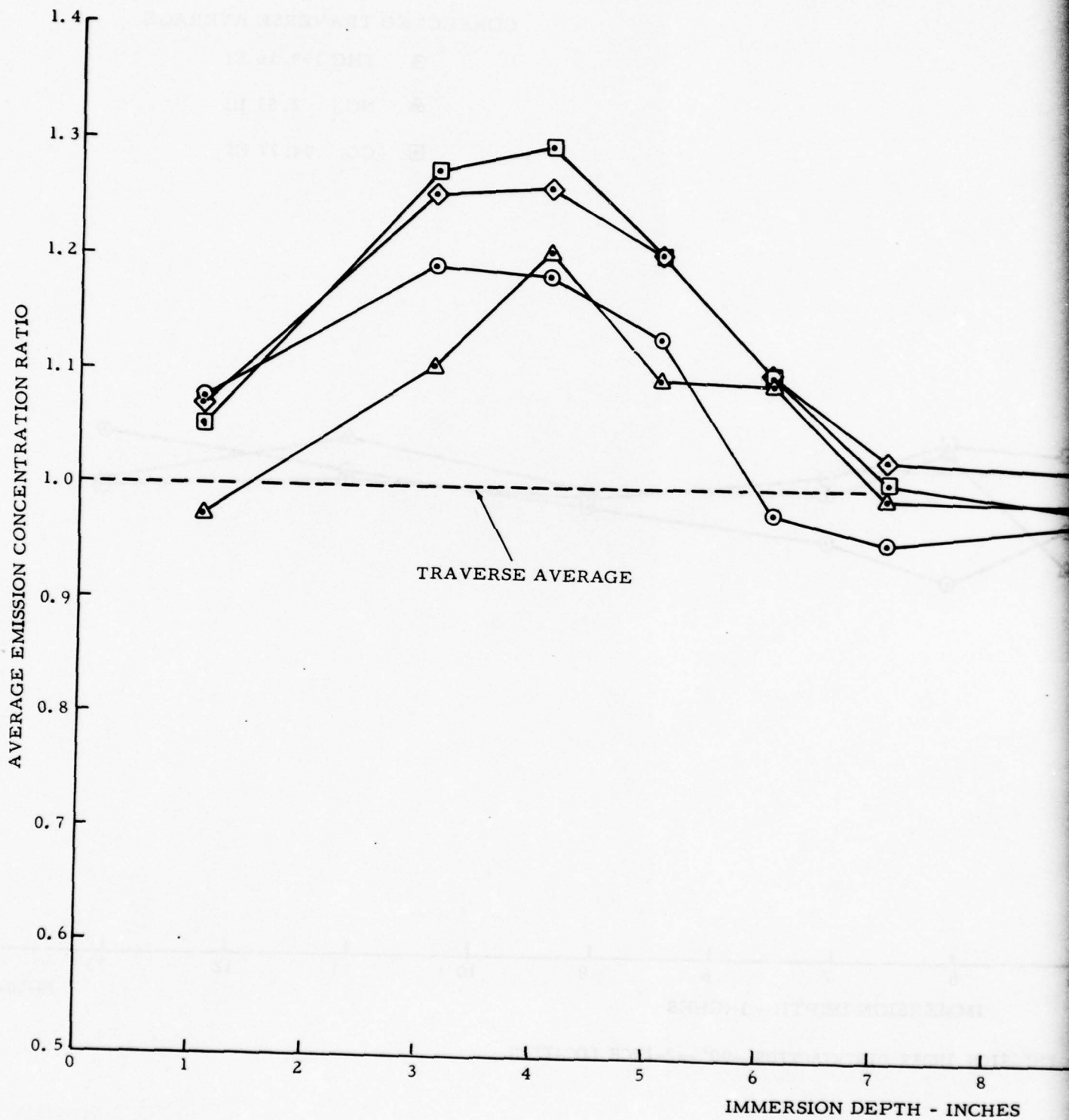


FIGURE 13. EMISSION CONCENTRATION DISTRIBUTION--90°--2

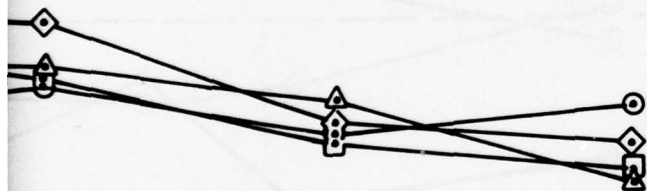
OBSERVED TRAVERSE AVERAGE

⊙ THC 2296.64 PPM

△ NO_X 9.76 PPM

◇ CO₂ 1.17 %

□ CO 706.42 PPM



9 10 11 12 13 14
79-10-14

2-INCH LOCATION

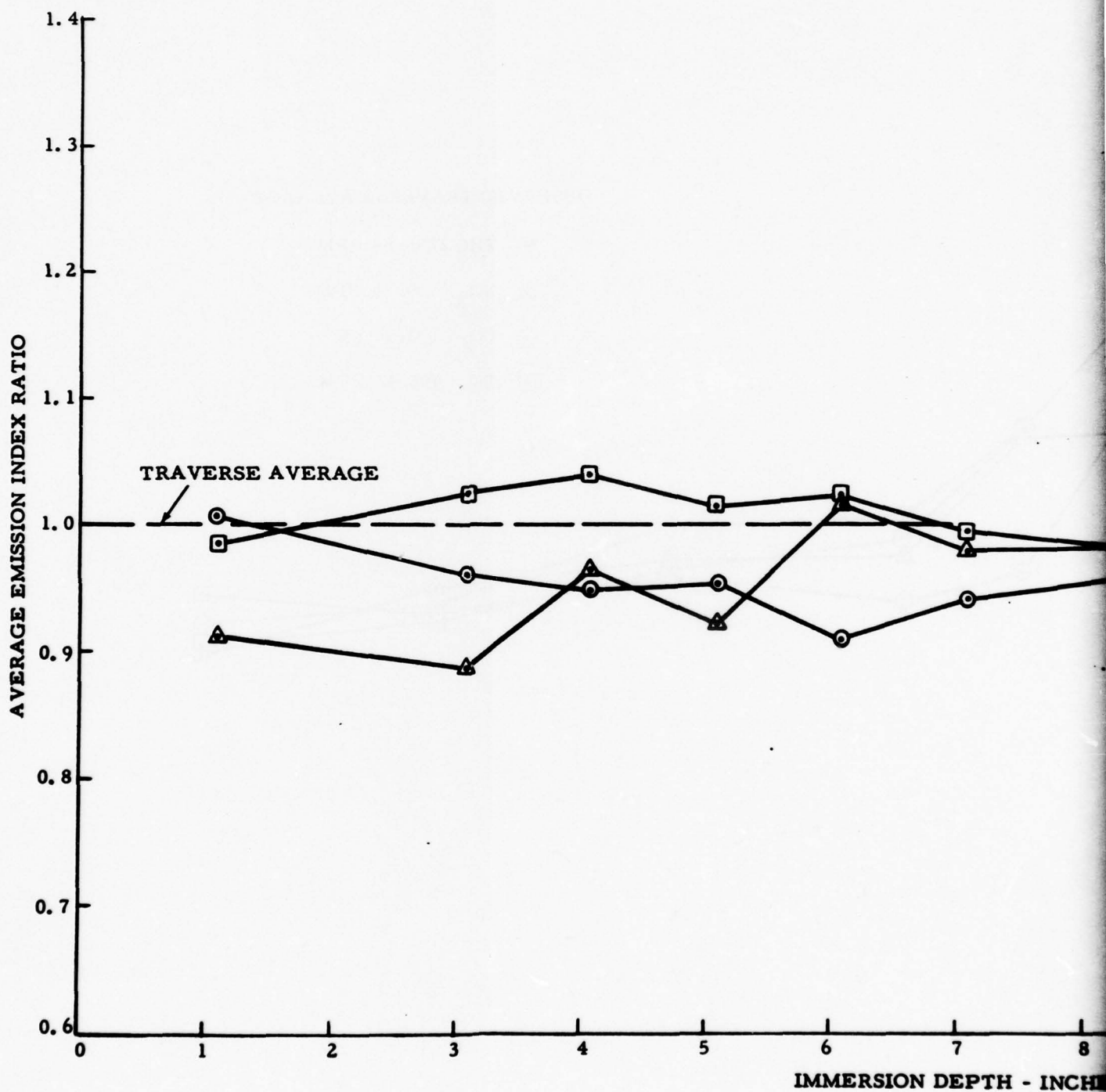


FIGURE 14. EMISSION INDEX DISTRIBUTION—90°—

CORRECTED TRAVERSE AVERAGE

● THC 159.16 EI

△ NO_X 2.51 EI

□ CO 94.77 EI



9 10 11 12 13 14

79-10-15

HES

—2-INCH LOCATION

2

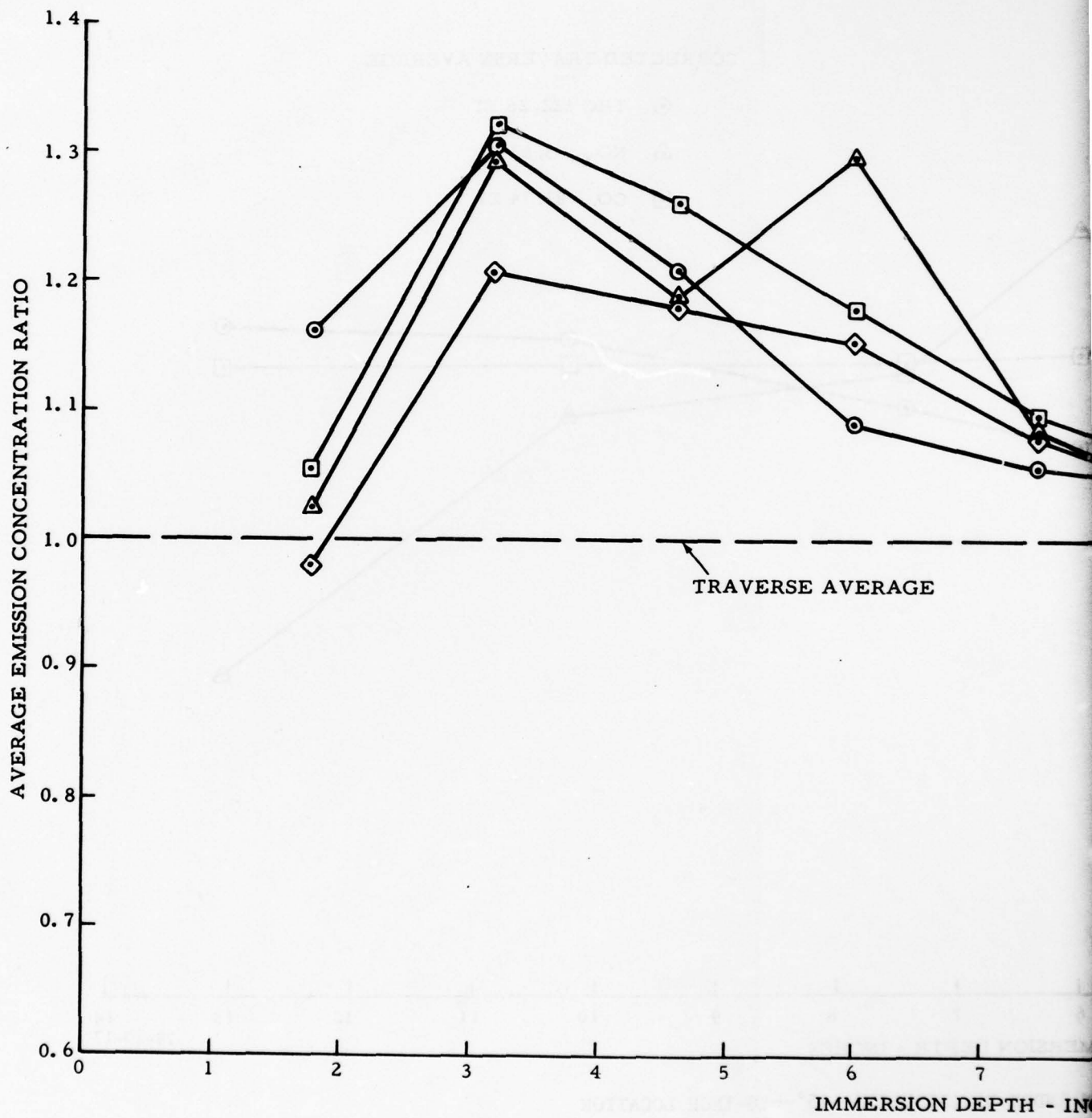


FIGURE 15. EMISSION CONCENTRATION DISTRIBUTION-

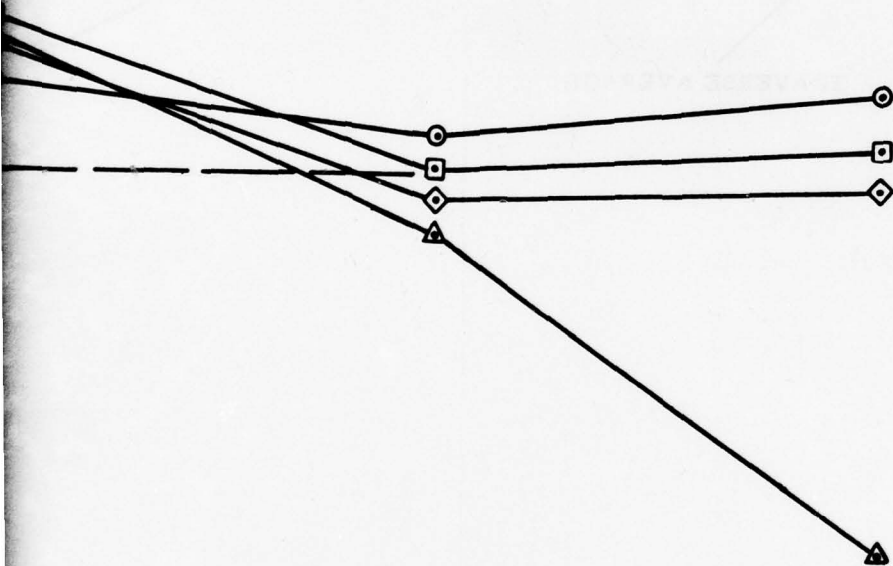
OBSERVED TRAVERSE AVERAGE

⊙ THC 1609.6 PPM

△ NO_x 12.93 PPM

◇ CO₂ 1.19 %

□ CO 593.95 PPM



8 9 10 11 12 13 14
INCHES 79-10-16

ION--45°--10-INCH LOCATION

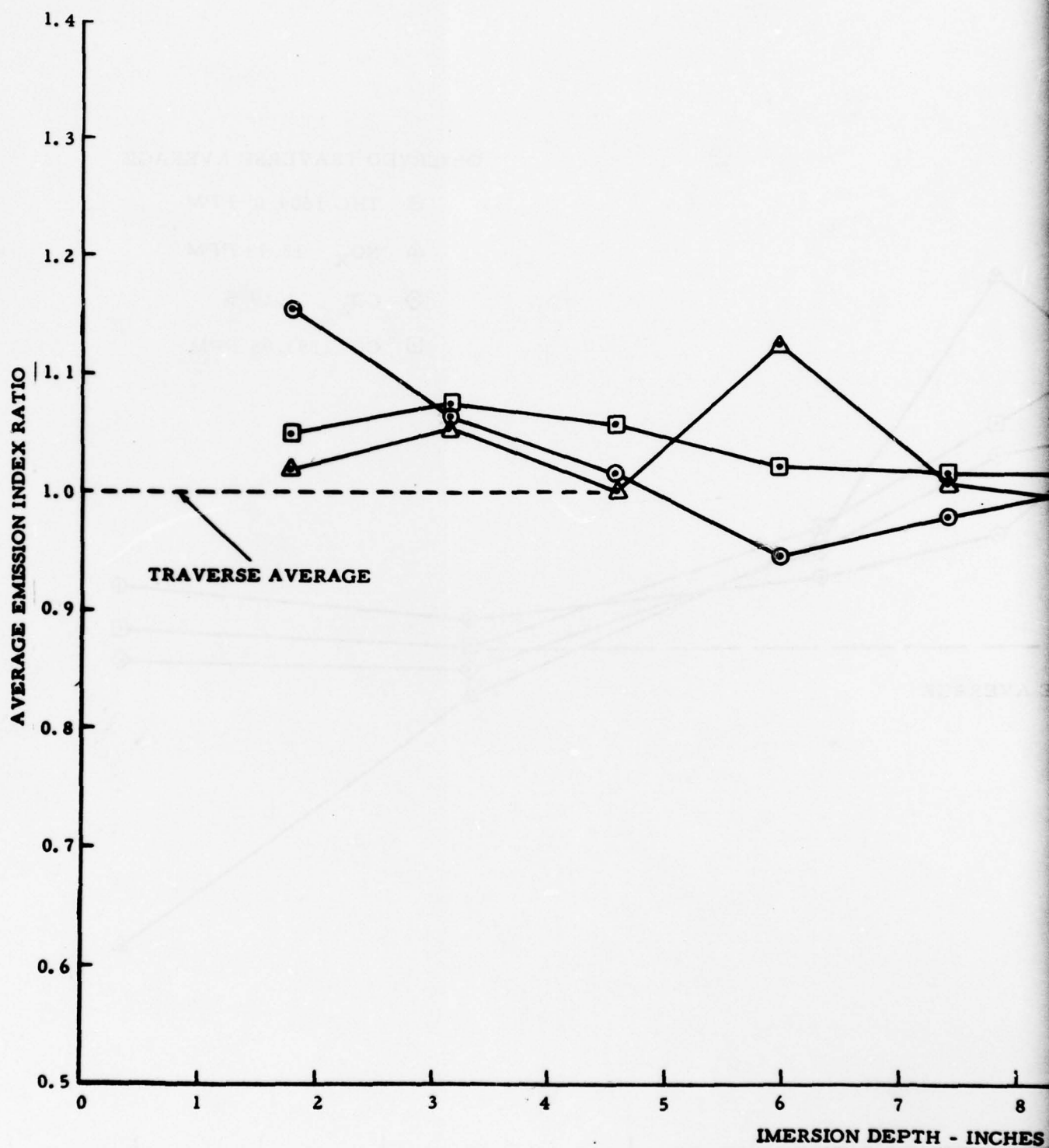


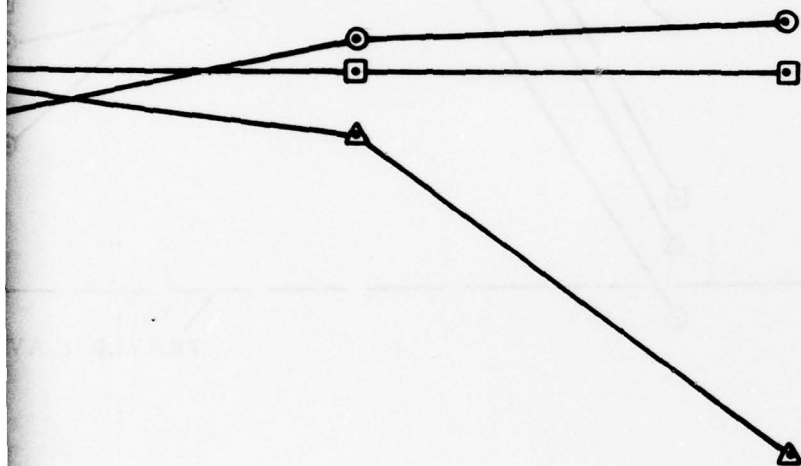
FIGURE 16. EMISSION INDEX DISTRIBUTION--45°

CORRECTED TRAVERSE AVERAGE

⊙ THC 122.26 EI

△ NO_x 3.53 EI

□ CO 83.74 EI



8 9 10 11 12 13 14
HES 79-10-17

-45°--10-INCH LOCATION

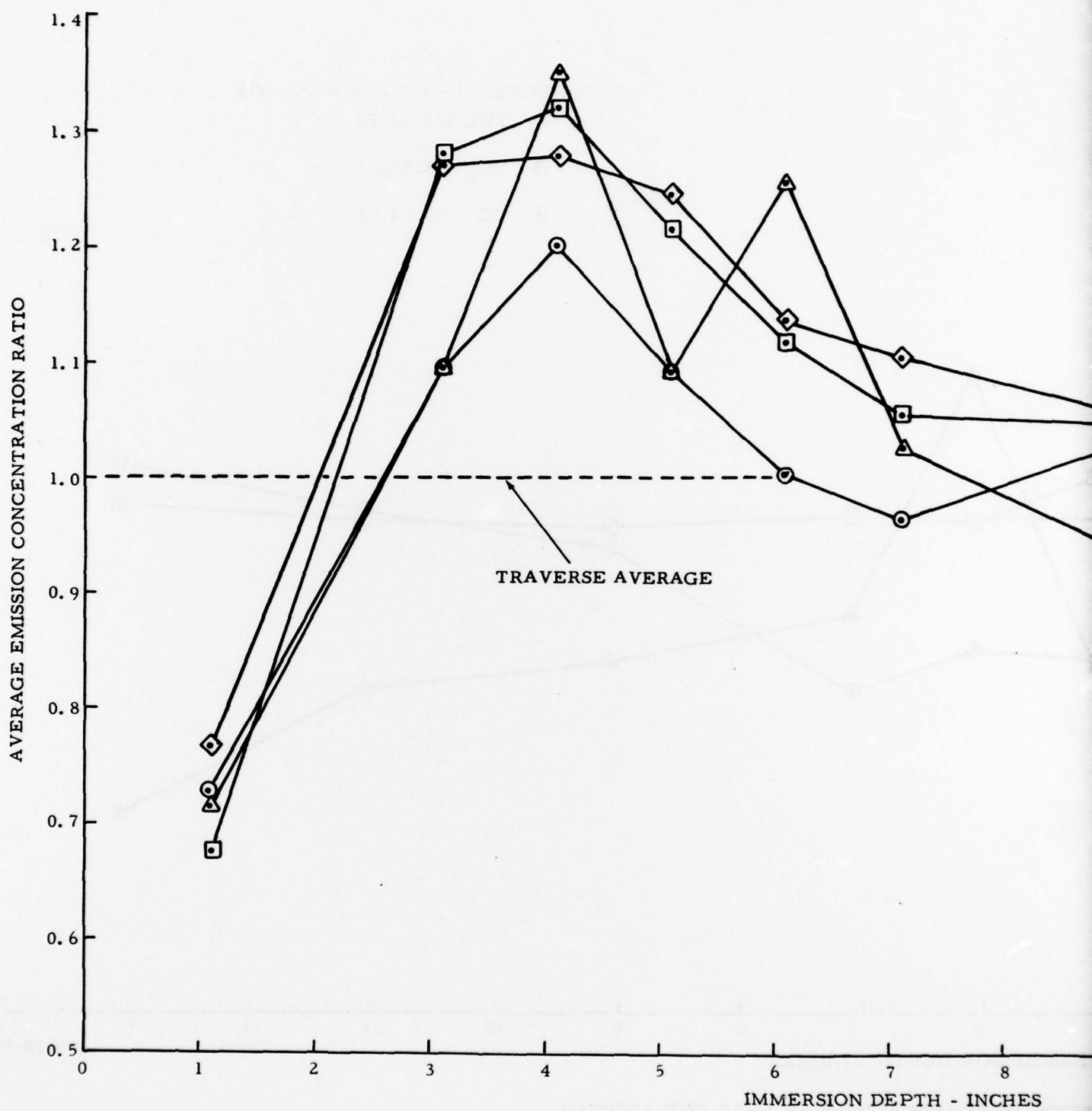


FIGURE 17. EMISSION CONCENTRATION DISTRIBUTION--90°--10-

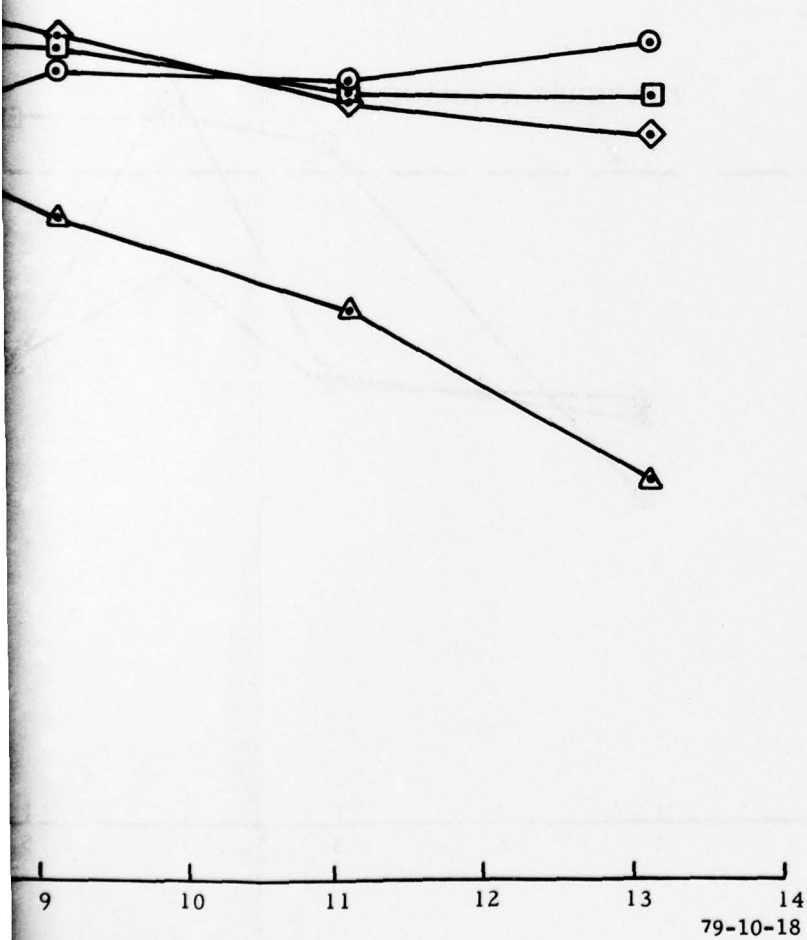
OBSERVED TRAVERSE AVERAGE

⊙ THC 1609.6 PPM

△ NO_x 12.93 PPM

◇ CO₂ 1.19 %

□ CO 593.95 PPM



INCH LOCATION

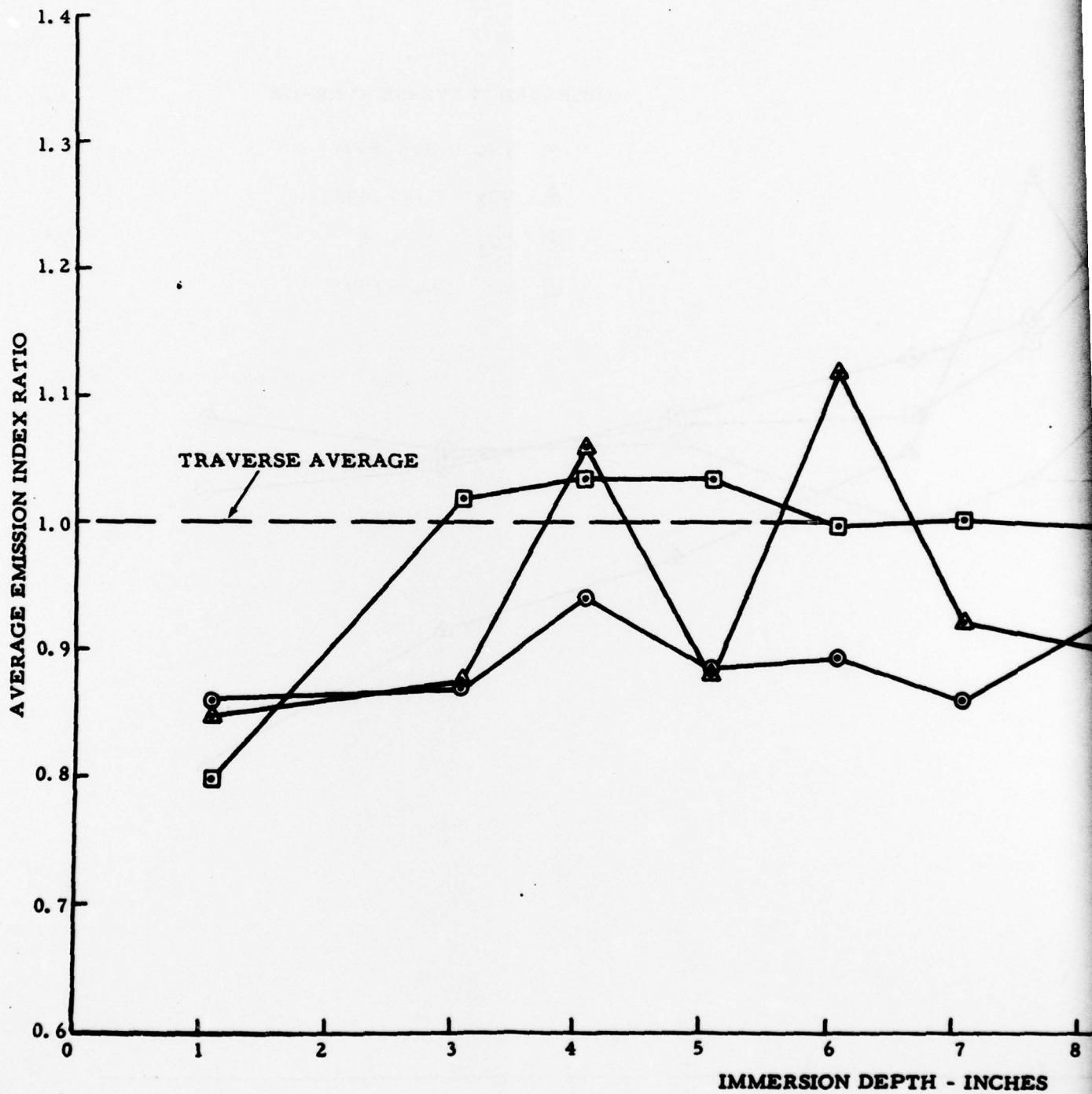


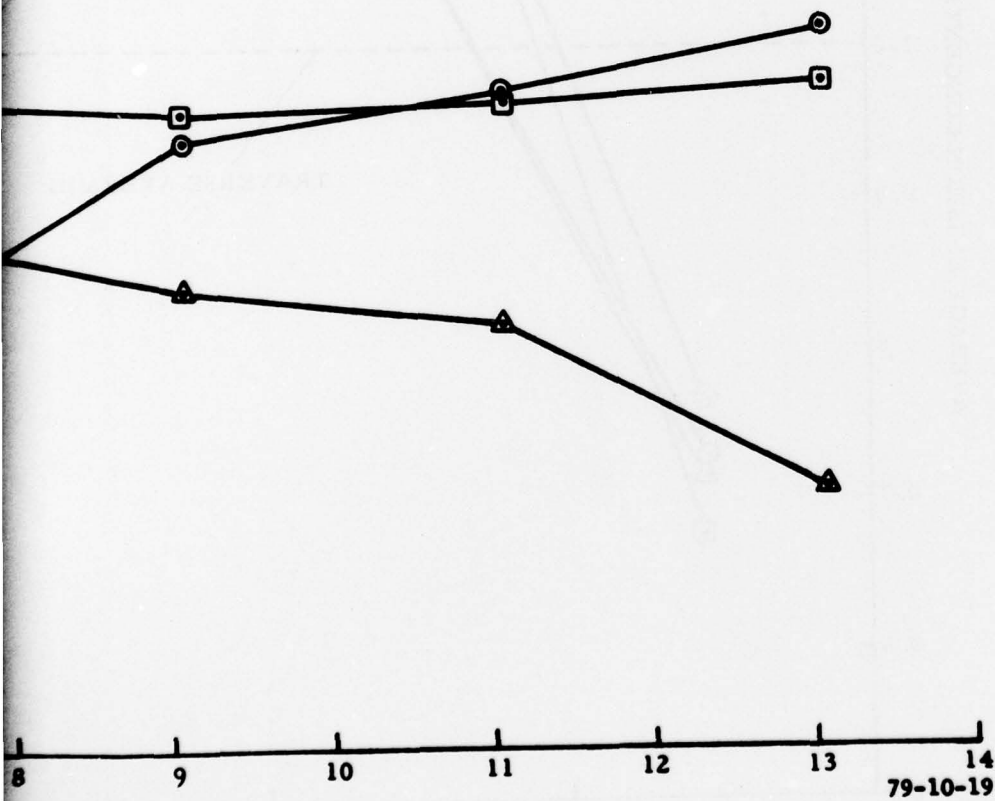
FIGURE 18. EMISSION INDEX DISTRIBUTION--90°--10

CORRECTED TRAVERSE AVERAGE

⊙ THC 122.26 EI

△ NO_X 3.53 EI

□ CO 83.74 EI



10-INCH LOCATION

APPENDIX

ENGINE PERFORMANCE AND EMISSION DATA BASE

○ POINTS LOCATED ON 2-INCH GRID

× ADDITIONAL POINTS FOR PROFILE EVALUATION
WHICH WERE NOT INCLUDED IN THE DETERMINATION
OF THE TRAVERSE AVERAGE

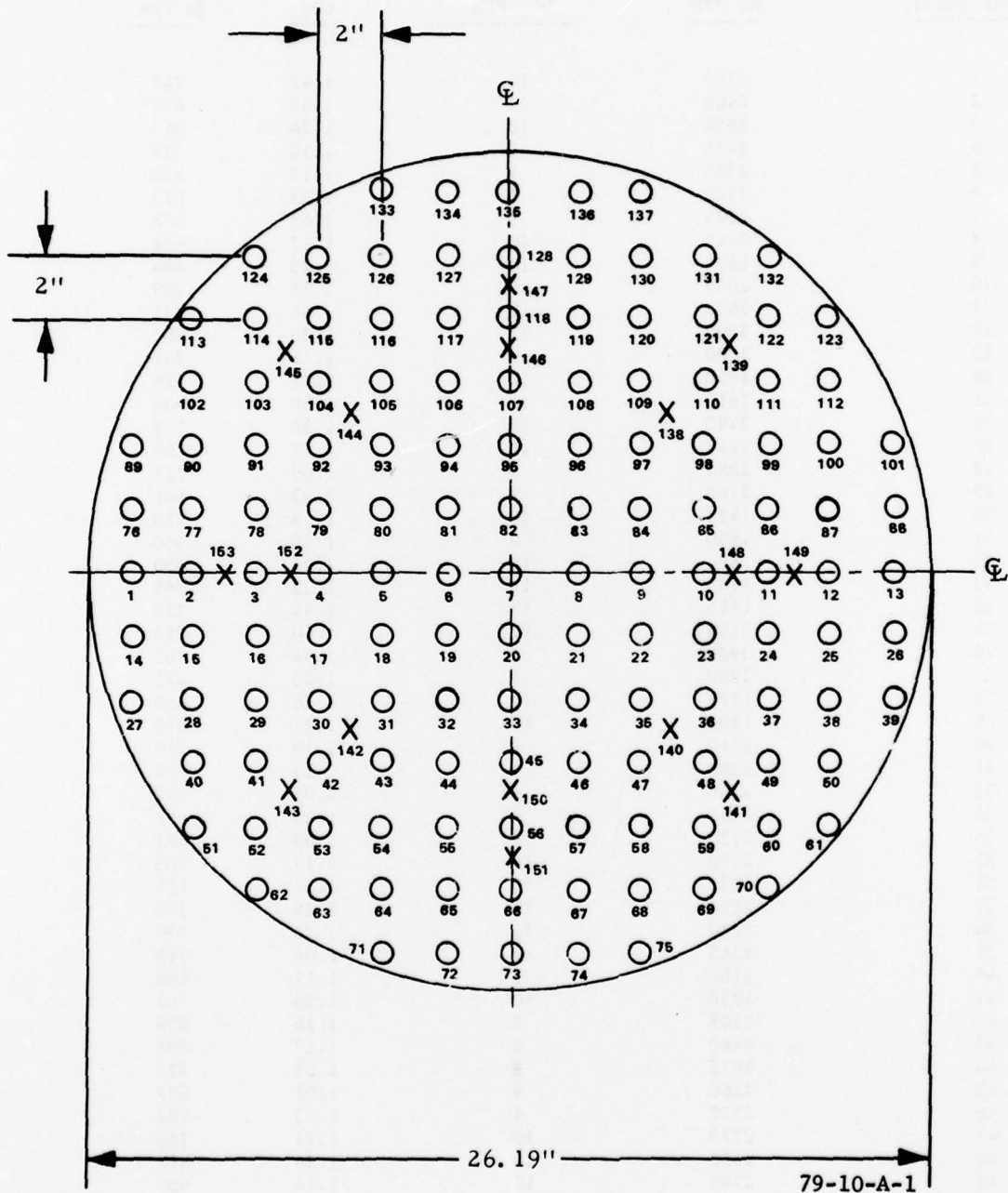


FIGURE A-1. IDENTIFICATION OF TRAVERSE EMISSION SAMPLE POINTS (153)

TABLE A-1. TRAVERSE EMISSIONS AT IDLE POWER--2 INCHES BEHIND THE NOZZLE

<u>Probe Posit.</u>	<u>HC PPM</u>	<u>NO_x PPM</u>	<u>CO₂</u>	<u>CO PPM</u>
1	1920	10	1.42	745
2	2400	12	1.58	877
3	2850	10	1.34	811
4	2475	9	1.19	722
5	2385	9	1.13	722
6	2325	9	1.05	613
7	2205	9	1.09	648
8	2040	10	1.17	654
9	1875	10	1.23	684
10	2055	10	1.25	709
11	2670	12	1.46	871
12	3300	11	1.36	886
13	3000	9	1.15	741
14	1650	10	1.32	629
15	2610	11	1.50	906
16	2490	10	1.30	779
17	2145	10	1.19	709
18	2280	9	1.09	722
19	2160	9	1.03	661
20	1920	10	1.13	710
21	1800	9	1.15	660
22	1860	10	1.21	690
23	2145	11	1.32	765
24	1815	13	1.44	720
25	2100	12	1.40	752
26	3900	7	.98	762
27	1200	9	1.05	475
28	1785	10	1.28	666
29	1800	10	1.21	630
30	2310	9	1.19	779
31	2280	9	1.11	722
32	2160	8	1.01	673
33	2160	9	1.26	678
34	2130	9	1.09	685
35	2130	10	1.17	703
36	2235	10	1.21	715
37	2190	11	1.26	740
38	2280	11	1.26	734
39	2265	9	1.09	710
40	2100	9	1.17	660
41	1950	10	1.26	702
42	2505	8	1.26	859
43	2460	9	1.17	806
44	2415	8	1.05	722
45	2280	9	1.07	697
46	2310	8	1.13	722
47	2370	10	1.21	760
48	2550	10	1.24	819
49	2790	10	1.24	880

TABLE A-1. TRAVERSE EMISSIONS AT IDLE POWER--2 INCHES BEHIND THE NOZZLE
(Continued)

<u>Probe Posit.</u>	<u>HC PPM</u>	<u>NO_x PPM</u>	<u>CO₂</u>	<u>CO PPM</u>
50	2550	10	1.26	785
51	1065	5	.79	451
52	2550	9	1.36	784
53	2850	9	1.40	872
54	2475	9	1.38	817
55	2475	9	1.38	791
56	2550	9	1.28	785
57	2400	8	1.26	753
58	1950	8	1.26	784
59	2715	8	1.48	871
60	2625	8	1.30	859
61	1575	6	.86	466
62	1200	5	.75	391
63	2100	9	1.30	772
64	1920	9	1.30	721
65	1890	9	1.32	721
66	2325	9	1.46	885
67	2880	9	1.44	993
68	1980	9	1.42	778
69	1860	8	1.28	740
70	1770	5	.79	508
71	1650	7	1.15	619
72	2430	8	1.38	838
73	2700	8	1.30	805
74	2595	21	1.40	872
75	2220	7	1.13	642
76	2400	8	1.34	798
77	2070	8	1.23	618
78	2430	12	1.30	727
79	2790	11	1.17	734
80	2730	10	1.07	691
81	2400	10	1.07	704
82	2385	10	1.09	673
83	2265	11	1.15	666
84	1965	12	1.26	715
85	1830	12	1.26	696
86	2100	11	1.19	678
87	2460	11	1.19	728
88	2460	10	1.09	667
89	1425	7	.90	497
90	1950	10	1.15	624
91	2280	11	1.17	672
92	2520	11	1.17	703
93	2625	11	1.09	691
94	2550	10	1.05	673
95	2550	11	1.13	691
96	2100	11	1.23	696
97	2205	12	1.15	709
98	2160	13	1.23	747

TABLE A-1. TRAVERSE EMISSIONS AT IDLE POWER--2 INCHES BEHIND THE NOZZLE
(Continued)

Probe Posit.	HC PPM	NO _x PPM	CO ₂	CO PPM
99	1920	11	1.23	696
100	2520	10	1.13	691
101	3525	9	.98	710
102	2700	10	1.15	741
103	2700	11	1.30	825
104	2850	12	1.28	852
105	2400	11	1.19	709
106	2100	11	1.21	684
107	1950	11	1.28	721
108	2025	11	1.26	721
109	2100	16	1.23	715
110	2250	13	1.32	811
111	2205	12	1.30	798
112	2700	11	1.25	740
113	4050	4	.29	177
114	3450	11	1.21	937
115	1800	12	1.26	715
116	1725	11	1.19	654
117	2025	11	1.19	715
118	2325	13	1.52	941
119	2775	13	1.11	728
120	2250	13	1.21	734
121	2700	13	1.36	886
122	3450	12	1.19	839
123	2325	8	.49	368
124	705	3	.20	137
125	3225	11	1.07	807
126	2025	12	.92	551
127	2025	13	1.23	709
128	2925	12	1.44	949
129	3450	13	1.21	866
130	3150	13	1.00	704
131	3150	13	.94	674
132	1950	7	.50	364
133	945	2	.29	197
134	1905	10	.90	552
135	2265	12	1.11	685
136	2400	10	.98	649
137	720	2	.24	140
Average	2296.64	9.76	1.17	706.42
138	1860	12	1.36	778
139	2775	12	1.50	927
140	2175	13	1.26	753
141	2625	11	1.36	900
142	2400	10	1.23	819
143	2400	11	1.40	857
144	2700	10	1.24	784
145	2850	10	1.42	934
146	1950	11	1.44	822
147	2850	12	1.56	990
148	2325	11	1.32	797
149	2825	12	1.48	933
150	2250	11	1.15	721
151	2700	12	1.36	878
152	2475	10	1.22	771
153	2400	12	1.48	863

TABLE A-2. TRAVERSE EMISSIONS AT IDLE POWER--10 INCHES BEHIND THE NOZZLE

Probe Posit.	HC PPM	NO _x PPM	CO ₂ %	CO PPM
1	870	8	1.02	389
2	1830	12	1.70	839
3	1950	11	1.44	724
4	1710	10	1.29	627
5	1740	10	1.27	633
6	1665	10	1.23	622
7	1695	10	1.19	605
8	1680	10	1.27	616
9	1530	11	1.33	639
10	1575	12	1.33	645
11	1875	12	1.44	705
12	2115	11	1.37	712
13	1590	7	.94	464
14	780	7	.92	315
15	1500	11	1.48	662
16	1440	11	1.37	604
17	1605	10	1.31	657
18	1605	10	1.19	634
19	1530	10	1.19	605
20	1410	10	1.23	599
21	1380	10	1.27	610
22	1440	11	1.31	639
23	1740	13	1.50	717
24	2055	14	1.63	691
25	2445	12	1.42	756
26	1845	7	.81	414
27	795	7	.77	281
28	1290	10	1.33	531
29	1440	11	1.40	598
30	1830	11	1.31	700
31	1785	10	1.23	646
32	1680	10	1.19	616
33	1650	11	1.23	628
34	1620	11	1.27	628
35	1500	12	1.33	651
36	1560	12	1.40	639
37	1605	12	1.42	627
38	1440	13	1.40	627
39	1290	8	.79	414
40	1395	11	1.21	565
41	1455	13	1.42	644
42	1740	13	1.44	724
43	1680	13	1.35	675
44	1500	12	1.23	628
45	1410	12	1.29	633
46	1470	13	1.37	687
47	1665	14	1.44	768
48	1800	13	1.35	762
49	1860	11	1.23	706

TABLE A-2. TRAVERSE EMISSIONS AT IDLE POWER--10 INCHES BEHIND THE NOZZLE
(Continued)

<u>Probe Posit.</u>	<u>HC PPM</u>	<u>NO_x PPM</u>	<u>CO₂ %</u>	<u>CO PPM</u>
50	2040	9	.92	572
51	960	7	.77	343
52	1725	12	1.35	669
53	1950	13	1.48	768
54	1575	13	1.50	668
55	1575	14	1.46	692
56	1710	13	1.44	699
57	1455	13	1.44	609
58	1860	18	1.44	762
59	2235	17	1.37	828
60	1575	16	1.29	645
61	1005	11	.79	366
62	765	10	.73	307
63	1050	14	1.14	489
64	1170	17	1.37	586
65	1230	19	1.50	686
66	1740	19	1.57	800
67	1545	19	1.52	717
68	1215	18	1.40	569
69	1800	12	.94	578
70	1050	8	.53	603
71	840	10	.81	352
72	1080	12	.96	409
73	1140	13	1.06	438
74	1110	11	.94	399
75	1110	10	.75	395
76	960	11	.96	418
77	1380	16	1.48	674
78	1560	17	1.42	644
79	1770	16	1.27	633
80	1725	16	1.19	616
81	1740	15	1.14	605
82	1860	15	1.12	588
83	1950	14	1.10	565
84	1815	15	1.16	587
85	1680	16	1.27	627
86	1620	17	1.31	633
87	1680	15	1.19	582
88	1410	11	.81	414
89	900	10	.79	357
90	1260	15	1.33	569
91	1485	15	1.27	570
92	1845	16	1.29	633
93	1920	17	1.27	663
94	1920	15	1.16	610
95	1740	16	1.23	598
96	1620	17	1.31	610
97	1605	18	1.33	645
98	1680	18	1.44	705

TABLE A-2. TRAVERSE EMISSIONS AT IDLE POWER-- 10 INCHES BEHIND THE NOZZLE
(Continued)

Probe Posit.	HC PPM	NO _x PPM	CO ₂	CO PPM
99	1785	17	1.33	669
100	2505	16	1.31	737
101	1725	9	.59	367
102	1440	13	1.06	500
103	2400	16	1.33	756
104	2250	18	1.44	768
105	1950	17	1.31	657
106	1725	17	1.27	610
107	1515	18	1.37	609
108	1605	18	1.40	638
109	1920	16	1.21	622
110	1995	18	1.42	743
111	2460	19	1.52	840
112	2370	12	.90	561
113	900	7	.53	268
114	1980	12	1.02	600
115	2280	18	1.46	834
116	1725	15	1.21	599
117	1410	17	1.31	581
118	1515	21	1.65	766
119	2070	19	1.48	794
120	1800	16	1.25	633
121	2235	15	1.14	658
122	2205	13	1.02	594
123	1350	7	.49	290
124	1215	8	.59	334
125	2770	12	.94	389
126	2175	14	1.08	646
127	1500	15	1.14	532
128	1350	15	1.44	692
129	2070	19	1.52	807
130	2280	16	1.23	719
131	1815	11	.85	490
132	1365	8	.53	303
133	1410	9	.57	357
134	1350	8	.61	272
135	1080	9	.65	316
136	1065	10	.73	347
137	960	9	.57	285
Average	1609.60	12.93	1.19	594.95
138	1650	18	1.42	692
139	2160	18	1.48	820
140	1650	17	1.42	736
141	2100	15	1.35	821
142	1650	16	1.40	705
143	1785	16	1.54	735
144	2070	16	1.29	669
145	2370	17	1.40	762
146	1695	17	1.31	645
147	1950	20	1.59	806
148	1770	17	1.37	730
149	2235	17	1.42	788
150	1440	16	1.42	644
151	1695	17	1.57	741
152	1560	15	1.33	645
153	1860	17	1.54	807

TABLE A-3. ENGINE PERFORMANCE AND TRAVERSE EMISSION INDICES

Run No.	3	7
Mode	Idle	Idle
Traverse Axial Location (in.)	2	10
Engine Inlet Temp., T ₂ (°F)	44	50
Specific humidity (grains H ₂ O/lb dry air)	28.08	44.11
Barometric Pressure (InHgA)	30.28	30.18
Engine Pressure Ratio (EPR)	1.016	1.017
Total Air Flow (lb/s)	98.0	108.0
Core Air Flow (lb/s)	37.33	41.14
Fuel Flow (lb/h)	973	1016
Compressor Discharge Temp., T ₄ (°F)	130	150
Compressor Discharge Press., (InHgA)	50.3	55.2
CO EI (lb/1000 lb fuel)	96.26	84.51
THC EI (lb/1000 lb fuel)	179.27	131.20
NO _x EI (lb/1000 lb fuel)	2.19	3.02
Corrected CO EI	94.77	83.74
Corrected THC EI	159.16	122.26
Corrected NO _x EI	2.51	3.53
Carbon Balance F/A	.007251	.006956
Measures F/A	.00724	.00686
Sample Efficiency, $\frac{F/A_{CB} \times 100}{F/A_M}$ (%)	100.2	101.4